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Multi-Band Printed Monopole Antenna Conforming Bandwidth Requirement of GSM/WLAN/WiMAX Standards

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Abstract—A novel multifrequency printed monopole antenna applied to GSM, WLAN, and WiMAX standards in laptop devices is developed. The novelty of the proposed monopole antenna is the simple design without using any reactive components, expensive substrate, or any additional hardware to operate in multi-band frequencies for laptop applications. It is noteworthy that the dimensions of the proposed antenna structure is only $0.105\lambda \times 0.05\lambda$, at lower resonating frequency 1.8 GHz, thus attaining a height of only 9 mm above the system ground. This antenna mainly incorporates an 'F'-shaped strip and a 'C'-shaped strip together printed on an FR-4 substrate. The coaxial feeding results in the generation of three bands with measured impedance bandwidth spanned in the range of (1.74–1.87 GHz) in lower band (f_l), (2.40–2.50 GHz) in a medium band (f_m), and (5.12–6.06 GHz) in upper band (f_u). Furthermore, the aforementioned antenna exhibits excellent radiation performances including gain around 4–5 dBi followed by efficiency greater than 80% in all the operating bands. The simulated and measured results are found in good agreement which demonstrates the applicability of proposed antenna for GSM 1800/WLAN/WiMAX applications in laptop devices.

1. INTRODUCTION

The proliferation of laptops devices clearly require antennas that can be very compact, simple in structure, can be installed completely within the product, and can conform to the bandwidth requirement of Global System for Mobile (GSM), Wireless Local Area Network (WLAN), and Worldwide Interoperability for Microwave Access (WiMAX) operations in laptop devices. The antennas for these requirements have been designed and developed in the literature [1–19].

Very small printed monopole antennas are reported in [1–3]. However, all these antennas are designed using reactive components which increases manufacturing complexity as well as power consumption. The meander antenna in [4, 5] exhibits the height of antenna 12 mm above the system ground. However, the next generation laptops demand antennas having height less than 10 mm due to its compact nature. The antennas reported in [6–8] have large dimensions of $96 \times 11.1 \times 0.5\,\text{mm}^3$, $46.5 \times 9.3 \times 1.6\,\text{mm}^3$ and $97 \times 11.1 \times 0.5\,\text{mm}^3$, respectively. Apart from large dimension, the antennas also use expensive substrates. The uniplanar antenna proposed in [9] has a dimension of $23 \times 6\,\text{mm}^2$ but is constructed using an additional adhesive ground plane which increases manufacturing complexity.

Compact monopole antennas are reported in [10–12]. The antenna proposed in [10] has a dimension of $23 \times 6\,\text{mm}^2$ and comprises an open-ring structure and a hook-shaped radiating element which is extended within this open-ring structure. The antenna in [11] comprises a C-shaped radiator and two meander shorting strips, which only has a small size of $35 \times 3\,\text{mm}^2$. The inverted 'E-shaped' monopole antenna proposed in [12] consists of two monopole radiating strips, an open ended tuning stub, and has the dimension of only $17.5 \times 6\,\text{mm}^2$.

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MIMO antennas for WLAN applications in laptop computer are reported in [13–15]. The antenna in [13] has a dimension of only $26 \times 3\,\text{mm}^2$ but not to mention that the reflection coefficient is less than $-6\,\text{dB}$ which is not a standard practice in laptop computers. The antenna in [14] has a large dimension of $45 \times 6\,\text{mm}^2$ and also consist of an additional isolation element. The MIMO antenna proposed in [15] is simple in design and has a dimension of only $17.5 \times 8\,\text{mm}^2$.

The standalone antennas for WLAN application proposed in [16–19] have very large dimensions and may not be favorable for their use in laptop computers.

Therefore, this paper presents a novel, compact, simple structure, low cost, easy to manufacture, multi-band printed monopole antenna for GSM 1800, WLAN, and WiMAX operations in laptop devices. The proposed antenna structure incorporates 'C'-shaped and 'F'-shaped strips which are printed together on a low-cost FR-4 substrate. This simple structure operates in multi-bands conforming to the bandwidth requirement of 1.8 GHz of GSM 1800, 2.4/5.2/5.8 GHz of WLAN, and 5.5 GHz of WiMAX bands in laptop devices.

2. PROPOSED ANTENNA GEOMETRY AND DESIGN

Figure 1 shows the geometric footprint of proposed antenna that is printed on a 0.4 mm thick FR-4 substrate with dielectric constant of 4.3 and loss tangent of 0.025. The dimensions of the proposed antenna are catalogued in Table 1. The proposed antenna of size $17.5(L) \times 9(W)\,\text{mm}^2$ is accommodated on the top edge of system ground. Here, the system ground of a 13-inch Laptop is considered which has a dimension of $200 \times 260 \times 0.2\,\text{mm}^3$ and is constructed using 91% Brass material. As shown in Figure 1, simple 'C'-shaped and 'F'-shaped monopole radiation strips are printed on a single FR-4 substrate. This structure adopts for small and low loss $50\,\Omega$ mini coaxial feed line with its central conductor connected to point 'P' located at the lower part of "C-Shaped" radiating strip and its grounding sheath soldered at point 'Q' on the system ground. Therefore, when the resonating 'C'-shaped strip and 'F'-shaped strip are embedded on a single FR-4 substrate and fed by a mini co-axial cable, it introduces the resonance for multi-band operations such as GSM, WLAN, and WiMAX. The proposed antenna is simulated using CST MWS software [20].

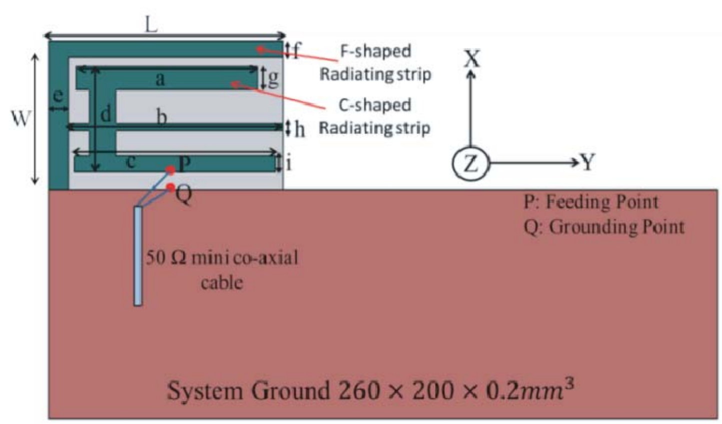


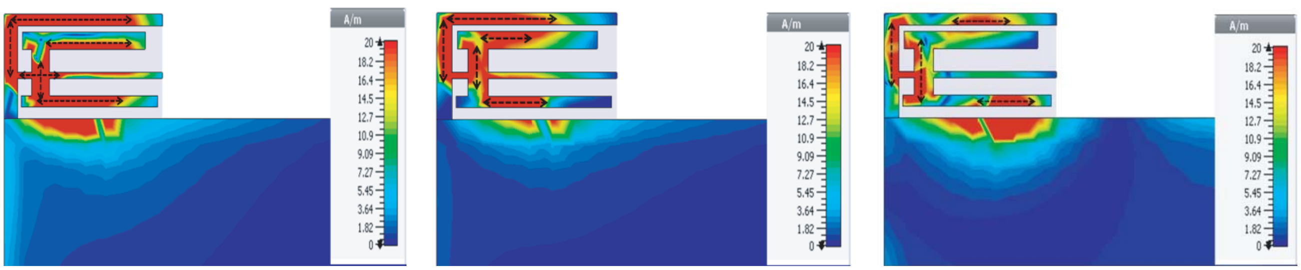
Figure 1. Proposed antenna attached on the top edge of system ground supporting 13-inch laptop display screen.

3. WORKING MECHANISM OF PROPOSED ANTENNA

To better understand the excitation of triple bands of the proposed antenna, the simulated surface current (A/m) distributions at resonating frequencies 1.8 GHz, 2.45 GHz, and 5.5 GHz of f_l, f_m, and f_u bands, respectively, are presented and analyzed in Figure 2. From the current distribution displayed in Figure 2(a), the resonating path for 1.8 GHz frequency is determined. From the current path, the

Table 1. Dimensions of proposed antenna.

Parameters	Values (mm)	Parameters	Values (mm)	Parameters	Values (mm)
L	17.5	c	15.1	g	01.5
W	09.0	d	06.5	h	00.5
a	13.6	e	01.5	i	01.0
b	16.0	f	01.0		



(a) (b) (c)

Figure 2. Simulated Surface current (A/m) distribution of proposed antenna. (a) At 1.83 GHz. (b) At 2.45 GHz. (c) At 5.5 GHz.

resonating length for 1.8 GHz is calculated as:

$$L_1 = \frac{3}{4}L + \frac{W}{2} + \frac{a}{2} + \frac{d}{2} + \frac{3}{4}c \tag{1}$$

From the above equation, the length of the resonance at 1.8 GHz is calculated as 39 mm. The obtained length is quarter wavelength long as below in Equation (2).

$$f = \frac{c}{4L\sqrt{\varepsilon_{reff}}} \tag{2}$$

where c is the velocity of free space, and ε_{reff} is the effective dielectric constant which is calculated from the relative permittivity of substrate.

For 2.45 GHz resonating band, the resonating path is determined from the current distribution shown in Figure 2(b), and the corresponding length is calculated using Equation (3)

$$L_2 = \frac{L}{2} + \frac{W}{2} + \frac{a}{4} + \frac{d}{2} + \frac{c}{2} \tag{3}$$

From the above equation, the length of the resonance at 2.45 GHz is 27.45 mm which is approximately equal to quarter wave long using Equation (2).

For 5.5 GHz resonating band, the resonating path is determined from the current distribution shown in Figure 2(c), and the corresponding length is calculated using Equation (4)

$$L_3 = \frac{L}{4} + \frac{W}{2} + \frac{d}{2} + \frac{c}{4} \tag{4}$$

From the above equation, the length of the resonance at 5.5 GHz is 15.9 mm which is approximately equal to quarter wave long using Equation (2).

Therefore, from the analysis of surface current distribution, it is visualized that the proposed antenna has multi-bands which operates in f_l, f_m, and f_u bands and hence, suitable for wireless operations in the laptop computers.

4. PERFORMANCE CHARACTERIZATION OF PROPOSED ANTENNA

The design of proposed antenna is validated by fabricating the prototype as shown in Figure 3 and tested using ROHDE & SCHWARZ (9 KHz–16 GHz) Network Analyzer. The radiation performance including radiation pattern, gain, and radiation efficiency is tested in an $8 \times 4 \times 4\,\mathrm{m}^3$ calibrated anechoic chamber.

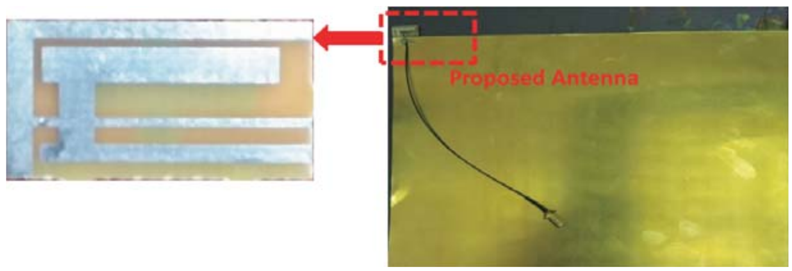


Figure 3. Fabricated prototype of proposed antenna mounted on system ground.

4.1. Reflection Coefficient (S_{11}) dB

Figure 4 shows the simulated and measured S_{11} for the proposed antenna. A good agreement between simulated and measured S_{11} in f_l and f_m is seen, whereas a small deviation at resonant mode of 5.5 GHz of f_u band is observed, which may be due to soldering and fabrication tolerances. Three successful resonant modes with amplitude of S_{11} better than 10 dB are measured at about 1.83 GHz, 2.45 GHz, and 5.5 GHz. The first resonance at 1.8 GHz covers GSM 1800 band; the second resonance satisfies 2.4 GHz Bluetooth/WLAN; and the third resonance covers 5.2/5.8 GHz WLAN and 5.5 GHz WiMAX bands. Table 2 shows the operating bands of the proposed antenna.

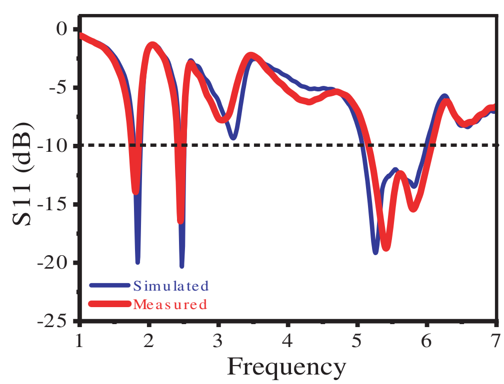


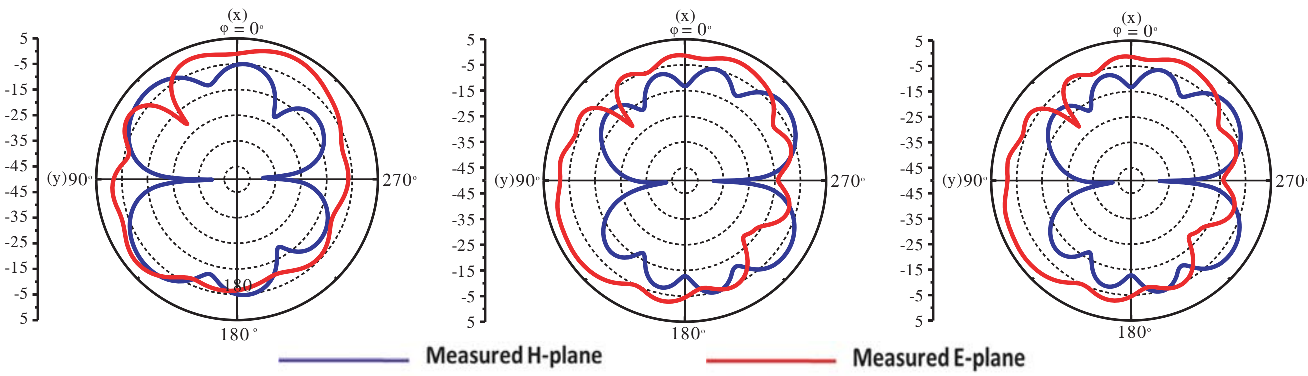
Figure 4. Measured and simulated reflection coefficient of the proposed antenna.

Table 2. Operating Bands of proposed antenna.

	Operating Bands in GHz	
	Simulated	**Measured**
f_l	1.75–1.89	1.74–1.87
f_m	2.39–2.51	2.40–2.50
f_u	5.05–6.00	5.12–6.06

4.2. Measured Radiation Patterns

The measured polar plot of radiation pattern of proposed antenna as a function of azimuth angle ($\varphi = 0°$) in x-y plane is plotted in Figure 5. In Figure 5, the E-plane and H-plane radiation patterns are measured at resonant modes of 1.8 GHz, 2.42 GHz, and 5.5 GHz of f_l, f_m, and f_u bands, respectively. The E-plane pattern of all resonant modes is nearly omnidirectional in the x-y plane, whereas the H-plane pattern contributes dipole pattern forming bi-directional radiation pattern in the x-y plane. This confirms the applicability of proposed antenna for multi-band applications in the laptop computers.



(a) (b) (c)

Figure 5. Measured 2D radiation pattern of proposed antenna at x-y plane. (a) At 1.8 GHz. (b) At 2.42 GHz. (c) At 5.5 GHz.

4.3. Measured and Simulated Gain and Radiation Efficiency

The simulated and measured values of gain and efficiency of proposed antenna across three operating bands are shown in Figure 6, and their comparison is shown in Table 3. The gain is calculated using Friss formula as given below:

$$G_2(\text{dB}) = 20\log_{10}\left(\frac{4\pi r}{\lambda}\right) + 10\log_{10}\left(\frac{p_2}{p_1}\right) - G_1\,(\text{dB}) \tag{5}$$

where G_2 (dB) and G_1 (dB) are gains of the proposed and reference antennas, respectively; r is the distance between reference and proposed antennas; p_2 and p_1 are the received and transmitted powers of the proposed and reference antennas, respectively.

Table 3. Comparison of simulated and measured values of gain and radiation efficiency of the proposed antenna.

Covered bands (GHz)	Gain (dBi)		Efficiency (%)	
	Simulated	Measured	Simulated	Measured
f_l	4.50–4.75	4.25–4.40	80.00–83.0	78.20–81.1
f_m	4.60–5.0	4.35–4.75	82.69–84.98	79.93–82.60
f_u	5.00–5.45	4.75–525	82.59–87.98	79.15–83.50

From the above table, it is observed that there is minimal deviation between simulated and measured values of both gain and radiation efficiency in the desired bands. This deviation may be due to fabrication tolerances of proposed antenna. However, Table 3 concludes that the proposed antenna exhibits a stable gain around 4–5 dBi and excellent efficiency greater than 80% across all the operating bands. This proves that the proposed antenna has good signal reception quality which is essential for wireless operations in laptop computers.

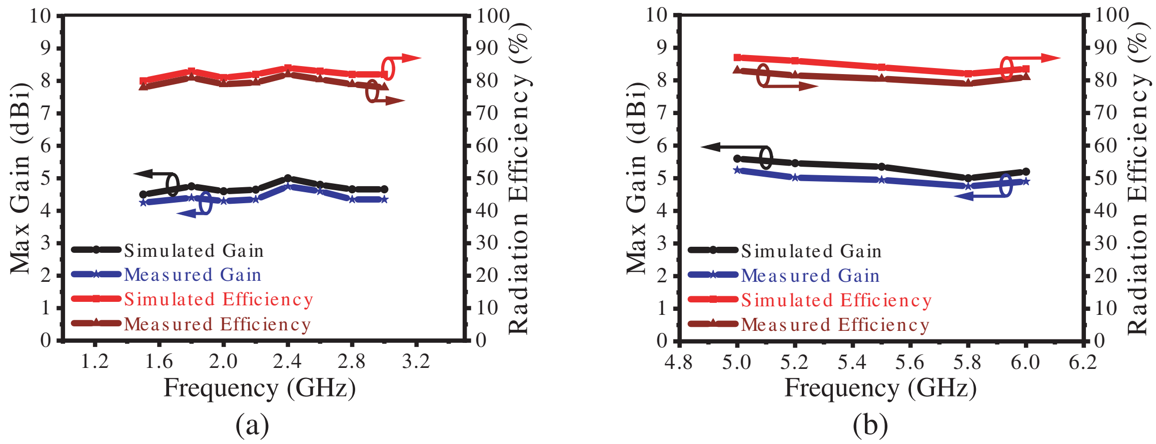


Figure 6. Measured and simulated gain and efficiency of the proposed antenna. (a) At 1.8 and 2.4 GHz. (b) At 5.5 GHz.

5. PERFORMANCE COMPARISON OF PROPOSED ANTENNA

To validate the potency of proposed antenna, Table 4 presents the performance comparison of the proposed antenna with other recently reported literatures. In this table, performances such as antenna size, operating bands, gain, and efficiency across the operating bands are compared. Here, it should be

Table 4. Comparison of proposed antenna with existing state of art.

Ref.	Size (mm^3)	Operating Bands (GHz)	Gain (dBi)	Efficiency (%)	Remarks
[1]	$30 \times 4 \times 0.8$	2.4/5	5.4/3.8	68/65	Uses reactive component
[2]	$20 \times 3 \times 0.4$	2.4/5	4.3/5.9	65/75	Uses reactive component
[3]	$20 \times 5 \times 0.8$	2.4/5.8	4.3/5.6	78/78	Does not cover the entire 5 GHz band
[4]	$12 \times 6 \times 0.4$	2.4/5	2.08/3.51	80/80	Low gain in 2.4 GHz band and height greater than 10 mm
[5]	$15 \times 12 \times 1.6$	1.5/2.4/3.5/5	0.072/5.35/3.03/4.4	56.2/97/96/85	Height greater than 10 mm
[7]	$46.5 \times 9.3 \times 1.6$	2.4/3.5/5	2.53/3.32/3.01	99/98/88	Uses expensive Taconic substrate
[9]	$23 \times 6 \times 0.4$	2.4/5	1.47/3.15	79/83	Uses additional ground plane
[11]	$35 \times 3 \times 0.4$	2.4/5	2.17/4.63	54/55	Low efficiency and uses holes and vias
This Work	$17.5 \times 8 \times 0.4$	1.8/2.4/5	4.40/4.75/5.25	81.1/82.6/83.5	Designed without using any expensive substrate or reactive components

taken into account that the proposed antenna has some obvious advantages such as small size, simple structure, stable gain and radiation efficiency in all the operating bands.

6. CONCLUSION

The design of a novel multi-band GSM, WLAN, and WiMAX monopole antenna for wireless operations in laptop computers is studied successfully. The proposed antenna has very a small size of $0.105\lambda \times 0.05\lambda$, at lower resonating frequency 1.8 GHz, simple structure, is easy to fabricate, and operates in 1.8 GHz GSM, 2.4/5.2/5.8 GHz WLAN, and 5.5 GHz WiMAX bands. The proposed antenna also exhibits the height of 9 mm above system ground which is promising for practical laptop computer applications. It shows nearly omnidirectional radiation characteristics along with overall gain and radiation efficiency well above 4 dBi and 80%, respectively. This confirms the applicability of the proposed antenna design for wireless operations in the laptop computers.

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